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Repair of Damaged Concrete with Epoxy Resins

By BAILEY TREMPER

The use of adhesives and binders containing epoxy resins by California Division of Highways in repairing concrete is described. Illustrations of their use in repair work are given. The discussion includes possible variations in formulation to secure wanted properties for specific uses, methods of application that are necessary to obtain strong and durable repairs, and a typical formulation for general use.

■ THE CALIFORNIA DIVISION OF HIGHWAYS has repaired damaged concrete with adhesives and binders containing epoxy resins as the essential component. The term adhesive is used to describe a formulation for bonding discrete portions of concrete. The term binder is used to describe a formulation used as a cementing agent to bind particles of aggregate into a mass that is originally plastic but later becomes rigid; epoxy resin is the binder in epoxy concrete just as portland cement paste is the binder in portland cement concrete. Actually the same epoxy formulation can be, and frequently is, used either as an adhesive or a binder.

The first description of epoxy resin appears to have been published by a Norwegian, Lindeman, in 1891. However, the manufacture of epoxy resins for commercial distribution is a development of the past decade. Epoxy resins are condensation products of epichlorohydrin and bisphenol. They contain oxirane groups and ether linkages. When activated with suitable curing agents, they form strong, chemically resistant structures having remarkable adhesive properties to concrete, wood, steel, and many other substances. Epoxy resins as presently manufactured, are available in a wide range of consistencies ranging from a virtual solid to liquids of relatively low viscosity. Those of higher viscosity have higher molecular weights. The color ranges from straw to amber.

At least four manufacturers in the United States now produce and market epoxy resins under license. As far as known, comparable grades of different producers have similar properties. The grades of epoxy

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resins are generally specified by viscosity and epoxide number or epoxy content. ASTM D 1652-59T gives methods of determining epoxy content, percentage of oxirane oxygen, and weight per epoxy equivalent of epoxy coating resins.

Epoxy adhesives were first used by the California Division of Highways in 1954. The discovery, originating in the laboratory of this division as far as known, that epoxy adhesives will form a strong, durable bond between fresh plastic concrete and old, hardened concrete, has greatly extended the usefulness of this compound as a repair material.

MATERIAL REQUIREMENTS

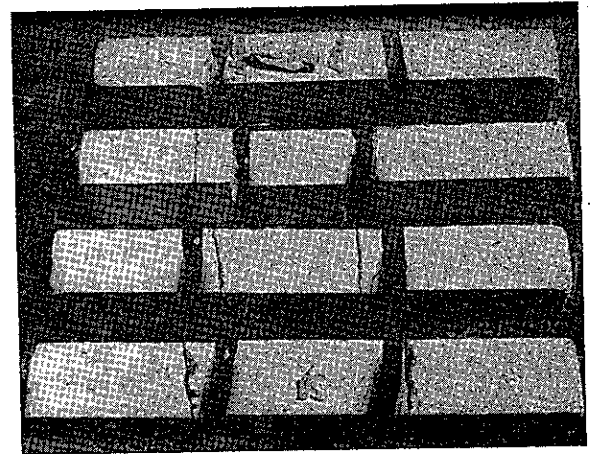
Only the resins of low viscosity find application as concrete repair materials. When cured, these resins are exceedingly strong but, without modification, possess little flexibility, particularly in cold weather. Polysulfide polymers can be added to improve flexibility without serious sacrifice in strength. The bond strength of a properly formulated adhesive is greater than that of concrete. This has been demonstrated many times by cementing two parts of a broken beam together and loading it to failure in flexure. Rupture always occurs in the concrete, not in the adhesive bond (Fig. 1). Similar tests in shear or in tension result in failure of the concrete itself. When fresh concrete is cemented to old concrete, failure occurs in whichever portion of the concrete is the weaker, not in the adhesive bond.

Adhesives and binders for highway use are formulated of epoxy resin, a plasticizer, and a curing agent. Depending on the viscosity at the time of mixing, it is usually possible to incorporate a certain amount of finely ground inert filler such as talc or silica. The amount of filler that can be used depends on ambient temperature and the viscosity desired for application. Primary components of low viscosity are desirable from the standpoint of reduction in cost by the maximum use of filler and ease of mixing.

Epoxies cure with an exothermic reaction. Large masses harden more rapidly than do small ones. The time required for the compound to harden sufficiently to withstand applied load, therefore, depends on its mass and temperature. Moderate heat can be applied to accelerate curing.

For the repair of highways and bridges under traffic, it is desirable to secure hardening as quickly as possible, but this complicates the

Fig. 1—Broken concrete cemented with epoxy adhesive and later rebroken



mixing and handling of the compound since rapid hardening formulations also have a short pot life, or period after mixing before hardening starts. In general, small batches must be mixed and applied promptly.

It is obvious that the final combination of the ingredients must be accomplished at the site of the work. Although three components are generally used, the plasticizer and curing agent can be packaged together if they are mutually soluble. Some primary compounds will function both as a plasticizer and curing agent. It is possible to incorporate some filler in the packages if the conditions of use are known in advance. In general, it is desirable to incorporate most of the filler at the time of mixing and thus secure better regulation of the consistency. Pigment grade tinting colors can be added to match the concrete if desired.

Curing agents are generally amines and are available from a number of manufacturers. The choice of curing agent and the percentage used determines the pot life and the time required to harden.

PATCHING TECHNIQUES

In patching spalled areas with epoxy mortar, or epoxy concrete, the binder used by the California Division of Highways contains little or no filler and has a pot life of about 20 min at 70 F. Under favorable conditions the repair has been opened to traffic within 3 to 5 hr. In cool weather metal channels are placed over the repaired area and they are warmed with torches (Fig. 2).

The aggregates used in epoxy mortar and concrete must be surface dry as otherwise the mixtures will not harden. Using a fine sand in mortars, the ratio of epoxy binder to sand can be of the order of 1 to 7 by weight. The economy in using coarse sand is not great. If the volume of the repair is large enough, both coarse and fine aggregate



Fig. 2—Placing epoxy concrete (foreground). Warming epoxy concrete (background). Repair opened to traffic in 2 hr

can be used and the ratio of epoxy binder to aggregate can be as large as 1:18 by weight. Mixing may be accomplished by hand or machine methods. The amount of binder is regulated to produce a plastic mass with sufficient excess binder to wet the surface to which the patch is applied. Alternatively the surface to be repaired may be primed with adhesive. The mixture is pressed or tamped into place and the exposed surface is brought to grade by screeding or troweling. The cost of epoxy concrete is of the order of \$200 per cu yd. Nevertheless, it has been considered to be economical to use it in fairly large volume on heavily traveled structures such as the San Francisco-Oakland Bay Bridge.

If substantial volumes of repair work are involved and if traffic conditions permit, it is more economical to use portland cement concrete bound to the original work with a coating of epoxy adhesive (Fig. 3 and 4). It is believed to be essential in such work that the portland cement concrete have a low slump, not greater than 2 in. The concrete must be in place before the adhesive has started to harden as evidenced by the development of a tacky condition.

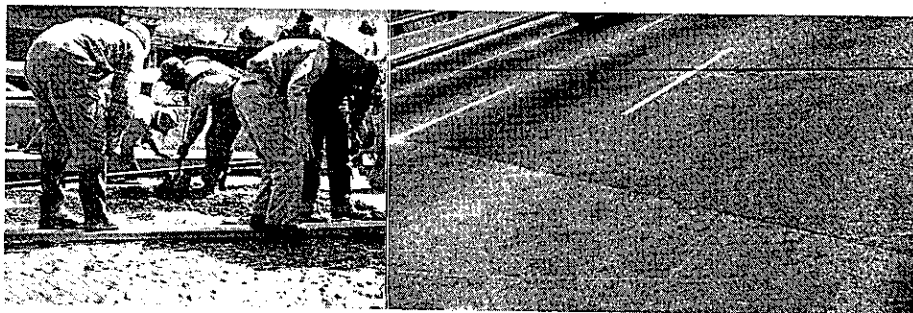


Fig. 3—(Left) Placing portland cement concrete on old concrete coated with epoxy adhesive. (Right) Repair after 15 months under traffic

Slower curing epoxy mixtures can be used as adhesives for fresh portland cement concrete since the time of hardening of the latter determines the time available for the adhesive to harden. Although curing agents are available to extend the pot life greatly, experience in the California Division of Highways has not been sufficient to conclude that they will produce an adequate degree of bond. New curing agents are being developed in considerable number and thorough testing and experimentation with them is warranted.

It is of utmost importance that the surface to which an epoxy adhesive is applied be scrupulously cleaned. Experience has shown attempts to remove oil stains from concrete with solvents have resulted in failure of bond. Sandblasting is the preferred method of cleaning. There are references to etching with dilute muriatic acid in distributors' literature, but the author cannot speak from experience in this matter. Concrete may be damp but must be free from surface moisture at the time the adhesive is applied.

Epoxy adhesives have been applied with squeegees, rollers, or inexpensive brushes which are discarded at frequent intervals. They are applied to a film thickness of about 40 mils (40 sq ft per gal.) with considerable excess on rough textured concrete.



Fig. 4a—Applying epoxy adhesive to bridge deck preparatory to placing portland cement concrete

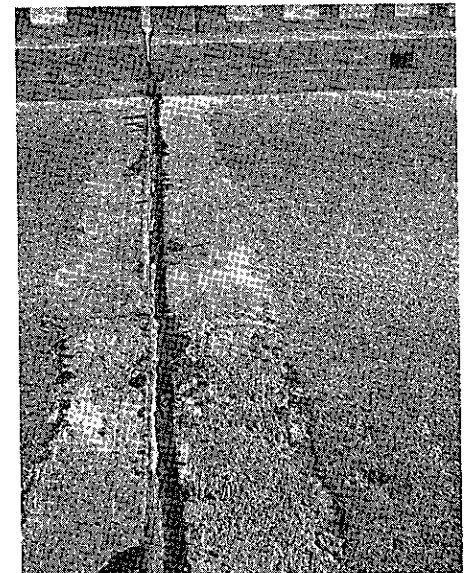


Fig. 4b—Typical condition of bridge deck before repair (foreground). Completed repair with portland cement concrete (background)



Fig. 5—Cracked bridge haunch repaired by injecting epoxy adhesive

The usual epoxy adhesive is too viscous for spray application but can be reduced to spraying consistency by the addition of aromatic solvents such as xylene. When a solvent is used it is important that the applied adhesive be allowed to stand until complete evaporation of the solvent has taken place. On the other hand, the waiting period must not be long enough to permit the development of set. Serious failures to secure bond to the new concrete have been observed when these precautions were not observed. Spray application using solvents is not recommended except under supervision by highly trained personnel.

Quick setting epoxy formulations should be mixed in small quantities, preferably not more than 2 gal. at a time. A dough mixer is convenient for this purpose. Disposable ice cream cartons are used in lieu of a metal mixing bowl to eliminate cleaning. A metal mixing paddle of appropriate shape is used.

Equipment used in mixing and applying adhesives and binders can be cleaned with aromatic solvents if done promptly. Once hardening has started, it is nearly impossible to remove the material except by strenuous mechanical means.

Cracks in concrete have been bonded (Fig. 5) by inserting small pressure fittings into drilled holes along the cracks at intervals of about 3 ft. The fitting is then cemented in place and the surface of the crack is sealed with adhesive leaving small vent holes. After this application has hardened, adhesive of low viscosity and containing little or no filler is injected through the fittings under considerable pressure.

A hand type grease gun or a pot operating under air pressure is used. A grease gun is preferred because of the higher pressure that can be developed. In addition to sealing cracks, this type of repair has been used to fill voids beneath metal expansion plates in bridge decks. Holes are first tapped in the metal plate and fittings are inserted. Surprisingly large quantities of adhesive have been injected into voids of this nature. If the plate is warmed with a torch, traffic can be permitted to pass over the repair within a few hours. The work has been eminently successful in eliminating looseness in bridge expansion plates.

The oldest work with epoxy adhesives performed by the California Division of Highways has been in cementing small reflective traffic markers to pavements. These have withstood heavy traffic at crosswalks for periods up to 5 years without failure in bond. This experience is cited as an illustration of proven durability of epoxy adhesives.

Epoxy installations in California have been made in regions of mild temperature except that recently a few have been made in locations where winter temperatures fall below zero. The author is not prepared to state at this time that the typical formulation yields adequate flexibility for exposure to cold weather.

The thermal compatibility of epoxy mortars and concretes with respect to the concrete to which they are applied needs more study particularly when relatively large areas are to be patched.

FORMULATIONS

The formulation most frequently used by the California Division of Highways both for an adhesive and a binder consists of:

Epoxy resin	10 parts by weight
Polysulfide polymer	4 parts by weight
Curing agent	1 part by weight
Filler	Variable

The epoxy resin has an epoxide number of 175 to 205 and a viscosity at 25 C of 5 to 9 poises.

The polysulfide polymer is a difunctional mercaptan having a specific gravity, 20/20 C of 1.27 and a viscosity at 25 C of 7 to 12 poises. Two curing agents have been used. One is 2,4,6-Tri (dimethylaminomethyl) phenol. The other curing agent is dimethylaminomethylphenol. The first agent yields a pot life of about about 20 min at a temperature of about 70 F. The pot life provided by the second agent is somewhat longer and is of the order of 45 to 60 min at 70 F. Filler is a finely ground, pigment-grade silica.

The epoxy resin is packaged separately. The polysulfide polymer and curing agent are mutually soluble and are packaged together.

A limited amount of construction involving epoxy adhesives has been performed under contract. One of the inspection problems has been in connection with securing thorough mixing of the two components of the adhesive. Recent specifications call for tinting the epoxy with titanium dioxide and the other component with carbon black. The mixed adhesive is required to be uniformly gray in color without visible streaks of black or white.

For some purposes the adhesive components have been made up with a predetermined amount of filler. In this case, finely divided talc has been used because of its antisetling properties. Colloidal silica in small amount has been added also to minimize sagging at the edges of horizontal applications or running in vertical applications. One manufacturer of reflective traffic buttons is packaging epoxy adhesive in a two part plastic bag. At the time of use, the separator is removed and mixing is accomplished by thorough kneading of the bag. A small opening is then made in the bag for dispensing purposes. The quantity of adhesive so packaged is about 1 lb which would be sufficient for small repair work.

Another type of epoxy combination is available commercially by a number of producers operating under license from the patent holder. It consists of two components, one of which contains a fluid epoxy resin; the other is "composed of a bitumen specially treated with an amine." Evidently the bitumen is largely coal tar. The mixed adhesive is rather low in viscosity and for some purposes filler can be added. Its pot life is relatively long, possibly 1 hr at 70 F. It requires from 2 to 10 hr to gain appreciable strength. Its main use to date has been as a thin resurfacing over slippery or otherwise deteriorated pavements and bridge decks. Sand or grit is applied to the surface to impart nonskid properties. Resurfacing of pavements and bridge decks with this type of composition is described in a Highway Research Board publication.¹ This publication is of particular interest because it describes a method of test for the strength or soundness of the surface on which it is proposed to construct the resurfacing. The test can also be used to evaluate the adequacy of preparation of the surface with respect to cleanness. According to literature circulated by one manufacturer of epoxy-bitumen (epoxy-coal tar) materials, it was placed at 17 locations on pavement, bridges, and airports involving a treated area of 37,650 sq ft during 1958. Epoxy-asphalt formulations are also being investigated.²

The cost of the liquid components of light colored epoxy adhesives or binders is about \$9 per gal. When furnished and packaged by commercial formulators, the selling price may be of the order of \$18 to \$25 per gal. The cost of epoxy-bitumen systems, which are black, may be considerably less.

Epoxy-coal tar compounds have excellent adhesion to steel and hardened concrete. Bond to fresh concrete is relatively poor as determined by laboratory tests in the California Division of Highways.

Epoxy resins as such, or after modification with plasticizers and curing agents, can present a potential dermatitis problem. The effect is most severe with the more fluid types of epoxy resins. Workmen should protect the hands with protective cream and rubber or disposable plastic gloves. They should wear coveralls or other suitable clothing. All skin areas contaminated by resins or uncured mixtures should be cleaned immediately. Individuals after suffering an attack of dermatitis may become unduly sensitized and smaller quantities of these materials may thereafter cause distress and make it more difficult to avoid the condition.

The use of epoxy compositions for repairing damaged or deteriorated concrete is receiving wide attention. Informal discussions at scheduled sessions have been held at the 38th and 39th annual meetings of the Highway Research Board. An ad hoc subcommittee of ASTM Committee C-9 has recommended the formation of a permanent subcommittee on epoxy formulations for concrete construction. The U. S. Air Force has issued a pamphlet³ on repairs to airfield rigid pavement using epoxy systems, to which are attached purchase descriptions for epoxy adhesive and epoxy binder for mortars and concretes.

Epoxy adhesives and binders should not be confused with other compounds such as polyvinyl acetates, polyesters, neoprene emulsions, and styrene-butadiene copolymer dispersions in water. Such compounds can function as adhesives, binders, or modifiers of portland cement paste and under certain conditions can develop strengths that are adequate for the work in hand. None, however, appears to possess fully the useful characteristics of properly formulated epoxy systems which include the ability to establish strong and permanent bonds to both fresh and hardened concrete, the ability to cure and harden in contact with moist concrete, negligible volume change on curing, the retention of cured strength in the presence of water, and outstanding resistance to weather and chemical agents.

ACKNOWLEDGMENT

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